A Novel Digital Over Current Relay with Variable Time-Current Characteristics for Protective Coordination

M. S. Choi, P. S. Cho, S. J. Lee, S. H. Hyun and K. H. Kim

Abstract - An over current relay(OCR), one of the most frequently used protective devices, has time-current characteristics (TCC) to control its trip time according to the current level. It is because an appropriate operating time interval is necessary for coordination with other protective devices. A set of TCC curves of an OCR is, in general, given by the supplier from which a curve is selected by the operator. Therefore, in many cases, it is impossible to consider the operation condition of the given power system exactly. A novel concept of an OCR is suggested in this paper. The proposed OCR has an internal correction module so that it may produce the most adequate TCC curve according to the given protective information for coordination with other devices. With the generated TCC curve, a variety of operation and coordination conditions can be taken into consideration in an effective manner. The suggested OCR is applied to a simple test power system to show very promising results from a coordination point of view.
Keywords - over current relay, protective coordination, time-current characteristics curve generation

1. Introduction

An over current relay (OCR) is one of the most widely used protective devices in a power system, which protects power equipment from excessive current caused by any kind of fault[3]. It receives the current value flowing through the lines or devices concerned and it sends a trip command to the circuit breakers(CB) so that the fault may be isolated from the rest of the system when the current exceeds the pick-up value determined in advance.

Since a distribution network consists of several kinds of protection devices, the coordination between them is a very important factor for successful protection.

For example, an OCR located near the source should have a larger pick-up value compared with an OCR on the load side. Furthermore, in case an OCR fails in tripping a CB, another OCR should perform the backup function with an adequate time delay. However, it is a very hard job to coordinate a set of OCRs in an optimal manner for several reasons. First, a distribution network inevitably encounters many kinds of faults and sudden changes in its loads or structure. Especially, changes in the normal operation condition require changes in the coordination scheme. However, it is almost impossible to satisfy every changing condition. An autonomous system is a candidate for overcoming this problem. Second, the nature of the existing OCR has its limit. The operation time in an electromechanical(EM) type OCR, the most broadly used type, is inverse to the current flowing. If an ME type OCR is solely in operation, this characteristic is not a problem. However, when a group of OCRs are working together to protect a network, there are several limits in coordination between them. Since a conventional OCR has only a few kinds of time-current characteristics(TCC) curves internally[1], the choice is limited to one of them. Therefore, it is quite difficult, or sometimes impossible, to meet the protective coordination condition in a satisfactory manner.

Recently, remarkable progress in digital technology had a great influence on protection systems. Digital relays are being substituted for conventional relays with many kinds of advantages over EM type relays. For example, a digital relay can be made to have its own intelligence for self-correcting, or an adaptive ability to a varying environment.

In this paper, a novel digital OCR is developed to solve the second problem. Unlike a conventional OCR, the TCC of the proposed OCR can be defined and corrected arbitrarily by the users. This feature allows effective coordination in the protection of a power system satisfying a variety of operation conditions.

This paper consists of five sections. In section 2, the general coordination scheme in a protection system is described, and the limit of conventional OCR use is also discussed. In section 3, a novel digital OCR is suggested including coordination schemes. The proposed OCR is applied to a sample distribution network to show its effectiveness, which is explained in section 4. The conclusions and discussion are summarized in the last section

Authors would like to express their sincere thanks to Korea Ministry of Science and Technology and Korea Science and Engineering Foundation for their support through ERC program.

Manuscript received: June 4, 2002 accepted: Sep. 16, 2002

M. S. Choi, P. S. Cho, S.J. Lee, and S.H. Hyun are with Next Generation Power Technology Center in Department of Electrical Engineering, Myongji University, Yongin, Kyongdo, Korea and K.H. Kim is with Division of information and communication of Catholic Sangji College, Andong, Kyungsangbukdo, Korea.

2. A Review of Operation and Coordination of an Over Current Relay

2.1 Over Current Relay (OCR)

As mentioned in the introduction, an Over Current Relay(OCR) is a device that protects power equipment from a high current caused by faults. A typical time-current characteristic(TCC) curve of an electro-mechanical(EM) type OCR, one of the most widely used types, is shown in Fig. 1. The operating time is decided by the input current along the TCC curve. There are two parameters in setting the EM type OCR: the tap and the time dial. The former determines the pick-up current value and the latter the operating time. Whatever the parameter values are set, operating characteristics of an OCR cannot go beyond one of the curves in Fig. 1[2].

Recent developments in digital technology have caused the replacement of the EM type with a new digital type that uses numerical equations to calculate the operating time of the relay. The equations used for each different kind of over current relay are as follows.

Definite time(DEFT) $t = t_p$.

Long , very inverse time(LT-VI) $t = \frac{6}{(I/IP)-1} \times tp$

Normal inverse time(NI) $t = (\frac{0.24}{(I/IP)^{0.4}-1} + 0.12) \times tp$

Very inverse time(VI) $t = (\frac{1.6}{(I/IP)-1} + 0.04) \times tp$

Extreme inverse time(EI) $t = \frac{8}{(I/IP)^2-1} \times tp$

In the equations, I represents the current input from the current transformer and t is the operating time. The pickup current (I_P) and time dial (t_p) determine the operating characteristics of the digital relay as seen in Fig.3. Commonly used digital relays have one of the curves in Fig.2 as their TCC.

2.2 Problems in Protective Coordination with conventional OCR

The operating parameters of an OCR are tap and time-dial, which will determine one of TCC curves in Fig.1, in the case of the EM type or in Fig. 2, in the case of the digital type, respectively. When an OCR is installed in the system, the operating parameters are determined in such a way that the OCR should act on the fault current; on the other hand, it stay calm with the load current under the pick-up current.

Furthermore, it should be in harmony with adjacent relays in the operation time. Fig. 3 shows an example of an OCR application to a simple distribution system. The curves above the line represent the operating time of each relay. It can be seen that there is a larger time delay as the distance from the fault is longer. This is because as the fault location is farther from the relay location, the impedance is larger, resulting in the smaller fault current and consequently slower operation according to the inverse characteristic of the TCC curve.

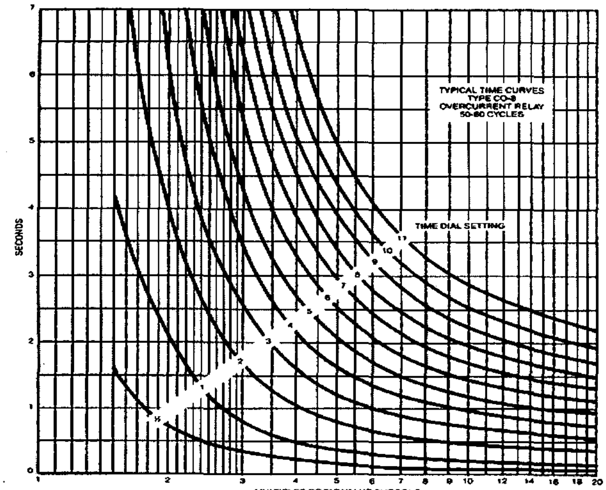


Fig. 1 A Time Current characteristics Curve of an OCR

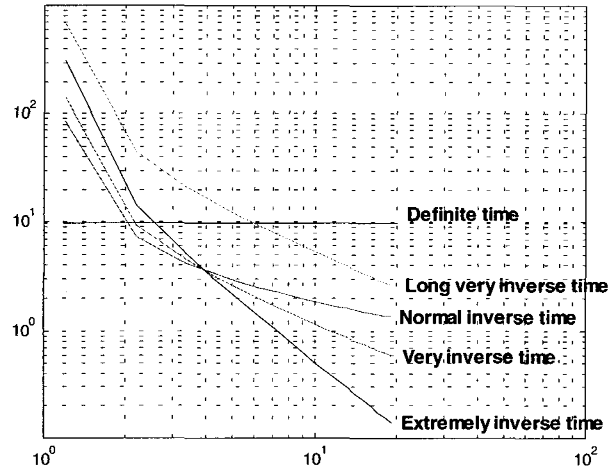


Fig. 2 Typical TCC's of digital over current relays

The pick-up setting which defines the minimum operating current is determined in accordance with the condition that it should be bigger than the load current and smaller than the minimum fault current it is supposed to detect. Once the pickup setting is fixed, then the time dial is to be determined considering the time coordination with other neighboring relays.

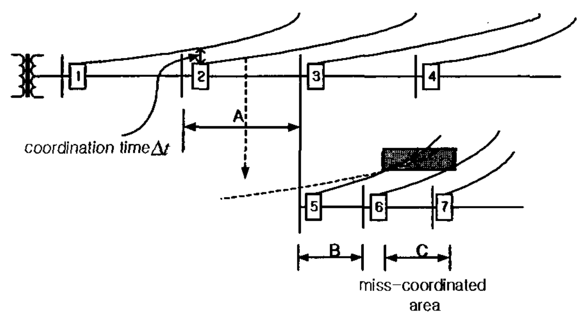


Fig. 3 An example of OCR Time Coordination

Let us discuss the time coordination using a simple example. Consider two OCRs, 1 and 2, in series as in fig. 3. When there is a fault in zone A, OCR 2, who is in charge of the primary protection, should operate. If it fails, then OCR 1 which would also experience the fault current as did OCR 2, should operate giving backup protection to OCR 2. In this case, OCR 1 should not operate before OCR 2 for the fault at zone A, which can be achieved by introducing a time delay called "coordination time (Δ t)" into the operating time requirement of OCR 1 in determining the time dial.

This time coordination should be satisfied for every pair of adjacent relays throughout the system. However, unfortunately, it is not always feasible. Consider the case shown in Fig.3, in which line sections with different lengths exist. Considering the length of protective zones, OCR 5 and OCR 6 have an extreme inverse TCC curve in order to meet the coordination condition, while OCR 1 and OCR 2 have an inverse TCC curve. In this case, there is a mis-coordination between OCR 2 and OCR 6 as can be seen in this figure. For the fault on zone C, OCR 2 will operate before OCR 5 when OCR 6 fails to operate, causing an unnecessary large outage area.

One solution to this problem is to raise the time dial of OCR 2 so that it may have a slower speed to give a time margin as seen in Fig.5. However, this will again cause the time dial change of OCR 1 in order to secure coordination with OCR 2. As a result, it will give a very slow speed to remove a fault on zone A and an even slower speed for the backup operation in case of the fault on zone B.

The resulting operating speed might be too slow to protect the line or transformer, causing damage due to the sustained duration of high fault current.

If an instantaneous type OCR is adopted together with an inverse type, as in Fig. 5, the problem could be weakened, but the same problem still remains since an instantaneous protection is not provided for the whole line.

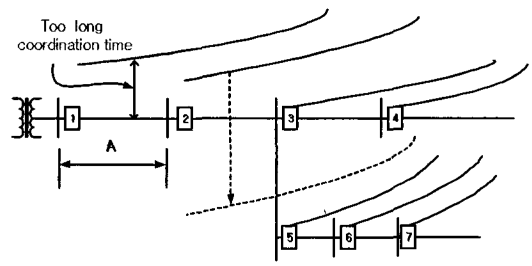


Fig. 4 An example of a mis-coordination problem

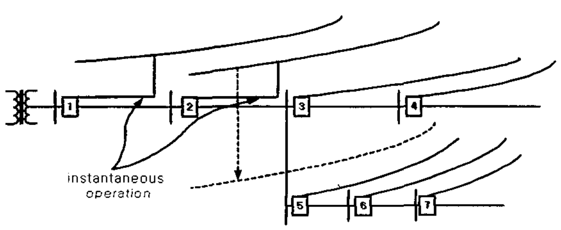


Fig. 5 Combination of Definite Time and Instantaneous Type

3. New Digital Over Current Relay

As explained in the previous section, a conventional relay has two setting values, pickup tap and time dial, and they determine the operating curve that has a fixed shape. Therefore, it is sometimes impossible to coordinate all relays with different shapes regardless of their types, the EM type or digital type. The setting and operation process of the conventional relay is described in Fig. 6.

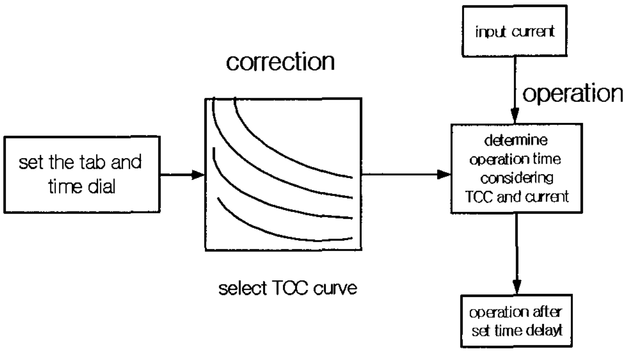


Fig. 6 Setting and Operation Process of Conventional Relays

In this paper, a new digital relay with flexible operating curve shapes are suggested. 'Flexible operating curve' means that the TCC curve can be changed so that users may define it as they want. The operating curve can be arbitrarily defined based on the operating points that guarantee the coordination. Fig.7 describes the setting and operation process of the proposed relay. The setting process is to determine the operating points that satisfy the coordination with other relays. The relay will then produce its own TCC curve that satisfies the given operating points exactly. The operating time of the relay will be determined according to this generated TCC curve.

An operating point is given by a pair of current and the operating time. Suppose five points A,B,C,D and E are required to secure the coordination as in fig. 8. The relay will generate the curve that passes through all these points and use it as its TCC curve. Consequently, this will guarantee coordination. Fig. 9. shows the case that applies such a new relay to OCR 2 in Fig. 4.

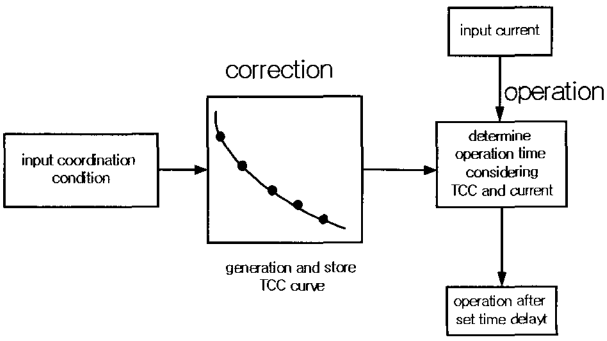


Fig. 7 Setting and Operation Process of Newly Proposed Relay

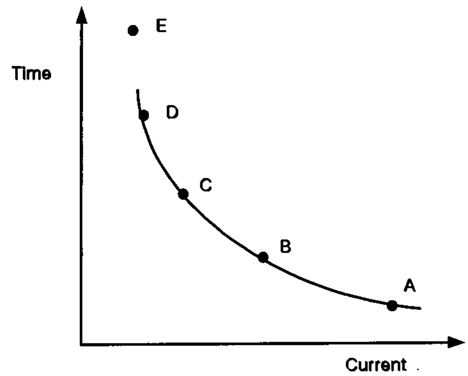


Fig. 8 TCC Curve satisfying Coordination Conditions

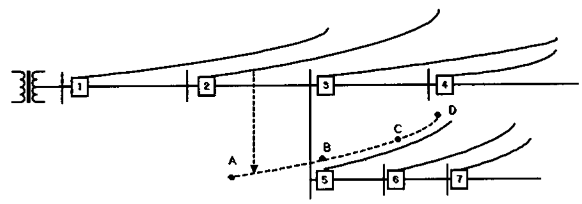


Fig. 9 Coordination Conditions

The remaining problem is how to obtain the operating points (A,B,C,D,E). It is explained as follows using an example of OCR 2. Point A is determined from the maximum fault current on zone A and the fastest time the relay should respond. The operating time of A is the minimum feasible value that the relay could have physically. The current value of point B is the maximum fault current on the next two adjacent lines on which two relays OCR 3 and OCR 5 are installed. OCR 3 and 5 are the ones that OCR 2 must coordinate with. Its operating time is determined by adding a coordination time to the bigger operating time of the above two adjacent OCRs at the maximum fault current, which happens at the fault at the relay location. Similarly, the maximum fault current at the next line section and operating time of associated relays determine point C. This similar process that secures the coordination repeats to determine point D. Point E determines the lower limit current of TCC that the relay should detect and its value is determined between the minimum fault current at the next lines and the maximum load current. Its operating time is set at a very large value. Once these five points are provided to the relay, it will generate a TCC curve as shown in Fig.8.

In using conventional EM or digital type OCRs, TCC curve should be selected among already given fixed shapes, which may cause mis-coordination. On the other hand, the proposed relay generates its own TCC curve that always satisfies the required coordination conditions. The effectiveness of the suggested relay is shown in a simulation given in the next section.

4. Simulation Results

The proposed relay is applied to a sample industrial distribution network of 22.9kV, given in Fig.10. In this figure, the inner part of the dotted line is of concern to us. We studied the protective coordination of the main transformer(MTr) and OCR 1 to OCR 6[4,5].

First, the conventional case is discussed. OCR 1 is functioning as a secondary protective device of the areas that OCR 2 and OCR 3 are protecting. In this case, if the TCC curve of OCR 1 is chosen for coordination with OCR 3 to be satisfied, it may break the damage curve of the MTr. Fig. 11 shows this situation where the straight line represents the damage curve of the MTr. The crossing point of the damage curve and TCC curve of OCR 1 means that the current set protection coordination may fail in the protection of MTr.

On the other hand, the proposed OCR can generate an adequate TCC curve to satisfy every coordination condition. The generated TCC curves of each OCR to meet the protection coordination condition are illustrated in Fig. 12.

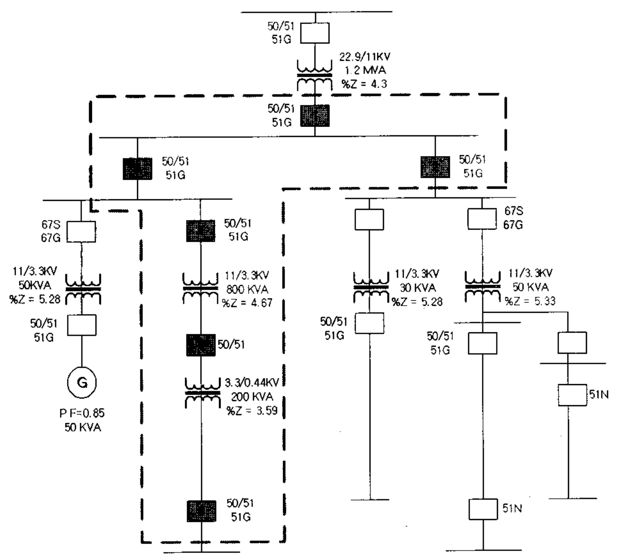


Fig. 10 Diagram of the studied network

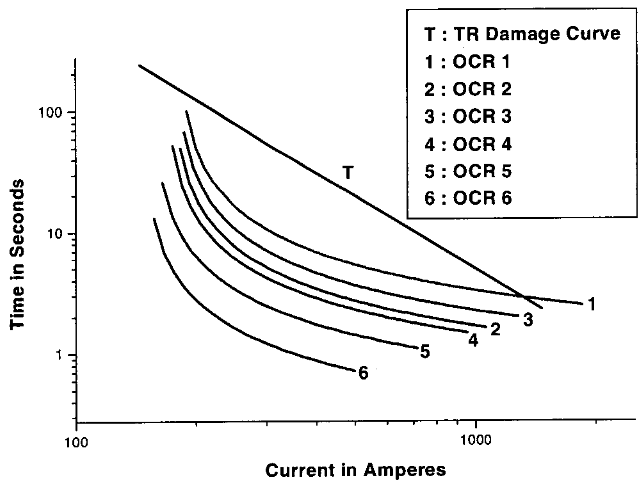


Fig. 11 Application of conventional OCR showing miss-coordination.

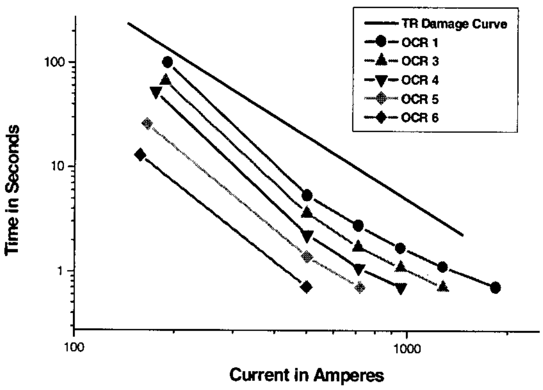


Fig. 12 Application of the proposed OCR satisfying coordination condition

5. Conclusions

In this paper, a novel digital Over Current Relay(OCR) is suggested for more effective and broad coordination protection. Conventional relays have a limited number of TCC curves with fixed shapes. Even if it is simple to set a TCC curve in installing the OCR, it may happen that the coordination condition is broken. On the other hand, the suggested OCR generates its TCC curves with several coordination points satisfied exactly. With the generated TCC curve, a variety of operation and coordination conditions can be taken into consideration in an effective manner.

It is shown, through simulations that the proposed OCR can protect the network with perfect coordination while conventional ones failed in coordination. It is thought that the more complicated the network becomes, the more effective the proposed scheme is. Especially, the proposed OCR is more useful in the automation of distribution systems.

Acknowledgement

The authors would like to express their sincere thanks to the Korea Ministry of Science and Technology and Korea Science and Engineering Foundation for their support through the ERC program.

References

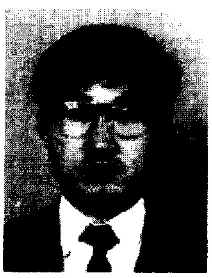
[1] J. Lewis Blackburn, "Protective Relaying Principle and Application Second Edition", Marcel Dekker, Inc., 1997.

[2] Charles V. Walker, "Electrical Distribution System Protection Third Edition", COOPER POWER SYSTEM , 1990.

[3] ARTHUR R. BERGEN, "Power System Analysis Second Edition", PRENTICE HALL, 1999.

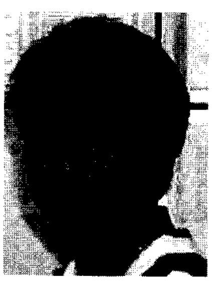
[4] "IEEE Recommended Practice for Protection and coordination of Industrial and Commercial Power Systems", Published by The Institute of Electrical and Electronics Engineer, Inc. Approved September 19, 1985 IEEE Standard Board.

[5] "IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants", The Institute of Electrical and Electronics Engineer, Inc. Approved December 2, 1993.



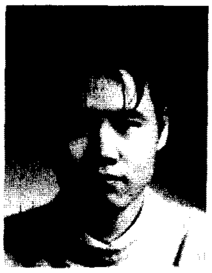
Myeon-Song Choi was born in Chungju, Korea, in 1967. He received his B.E., M.S., and Ph.D. degrees in Electrical Engineering from Seoul National University, Korea, in 1989, 1991, and 1996, respectively. He was a visiting scholar at the University of Pennsylvania State, in 1995. Currently, he is an associate professor at Myongji University. His major research field is power system control and protection, including artificial intelligence application.

Tel: +82-31-330-6367, Fax: +82-31-320-6816
E-mail: mschoi@mju.ac.kr



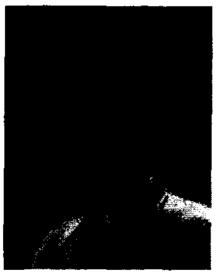
Seung-Ho Hyun was born in Seoul, Korea, in 1962. He received his B.E., M.S., and Ph.D. degrees in Electrical Engineering from Seoul National University, Korea, in 1991, 1993, and 1996, respectively. From 1996 to 2002, he worked for the Korea Railroad Research Institute, as a principle researcher and systems engineer. Currently, he is a research professor at Myongji University. His major research field is power system control, protection and artificial intelligence application to power system engineering.

Tel: +82-31-330-6814, Fax: +82-31-330-6816
E-mail: takeitez@mju.ac.kr



Pil-Sung Cho was born in Kwangju, Kyumggido, Korea, in 1973. He received his B.E. degree in Electrical Engineering from Myongji Unoversity, Korea. He has been working for his M.S. degree in Electrical Engineering in Myongji University since March, 2001. His are of interest is protective relay and protection system design of power systems.

Tel: +82-31-330-3290, Fax: +82-31-321-0271
E-mail: eastern@mju.ac.kr



Seung-Jae Lee was born in Seoul, Korea, in 1955. He received his B.E.and M.S., degrees in Electrical Engineering from Seoul National University, Korea, in 1979 and 1981, respectively. He received his Ph.D. degrees in Electrical Engineering from University of Washington, Seattle, U.S.A. in 1988. Currently, he is a professor at Myongji University and a chief of NPTC (Next-generation Power Technology Center). His major research field is protective relaying, distribution automation and AI applications to power systems.

Tel: +82-31-330-6362, Fax: +82-31-330-6816
E-mail: sjlee@mju.ac.kr

Ki-Hwa Kim was born in 1965. He received his B.E., M.S., and Ph.D. degrees in Electrical Engineering from Myongji University, Korea, in 1990, 1992, and 2002, respectively. Currently, he is an assistance professor at Catholic Sangji College. His research field includes electric devices, automatic control and computer application to power systems.

Tel: +82-54-851-3245, Fax: +82-54-857-9590
E-mail: kihwakim@hanmir.com.